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An Accurate Wireless Data Transmission and Low Power Consumption of Foot Plantar Pressure Measurements

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Abstract

The need for an accurate real time measurements for the foot plantar pressure, especially in gait analysis, is important and always under research because its flow in human health. This work proposes an accurate, very low power consumption wireless data transmission for monitoring and analyses the diagnosis based on two XBee S1RF Modules, one function as a base (receiver) which is connected to PC while the other collects the force/pressure sensors output and acts as a remote (data acquisition unit). The developed system consists of 4 resistive pressure sensors attached to an insole. Sensors are placed at four effective pressure points and interfaced with a wireless node and suitable conditioning circuit board. High speed rate and very low power consumption of data process made this technique useful for this application. Light weight lithium ion polymer, 16 gm, 2.96 W.h, 3.6V can operate the data acquisition and RF remote circuit with about 22.4 hours. A graphical user interface using MATLAB is used to plot data curves for different measurements.

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Keywords: pressure sensor; foot plantar measurement; data acquisition system;

1. Introduction

Wireless sensor networks (WSNs) technologies have been implemented in healthcare/medical application for many years[1–3]. It is driven by technology advances in low power system and medical sensors.

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This network consists large number of small sensors and multi-nodes. It also has one or more base stations to collect data from each sensor node to the user. The main features of WSNs are real-time transmission, accuracy, and comprehensive[2].

There are many wireless technologies nowadays, e.g. Bluetooth, ZigBee, radio frequency identification, Wi-Fi, 3G, and others. Zigbee is a new technology based on wireless standard 802.15.4. Zigbee has many advantages over other technologies such as good security as it provides data validation using encryption algorithm, low cost, low power consumption, large network capacity up to 255 devices, flexible working bandwidth (2.4GHz, 915MHz, and 868MHz), and the range covered from 10m to 100m, and etc. In medical application, foot plantar pressure has gained the interest of many researchers because it is useful in various applications, e.g. gait analysis[4–6], rehabilitation and support system[7], athletes' performance analysis[8,9], and etc. Many devices have been developed to measure plantar pressure. However, there are significant differences in data acquisition system, and configuration of sensors (i.e. the number and arrangement of pressure sensor used in the devices based on application)[10]. In many applications, real-time and continuous monitoring i.e.: gait analysis, daily activities, etc. is required. Thus, wireless data transmission is recommended with limited cabling for on-line data transfer to a remote computing/storing unit[10]. Wireless data transmission allows the subject to feel comfortable, safe, and walk or stand in natural gait condition. In foot plantar pressure measurement, Crea *et al.*[4]have developed a foot insole using optoelectronic pressure sensitive technology for real-time monitoring during walking. A wireless transmission used to transmit the data via Bluetooth connection. Very low current absorption allows the system to be operated continuously for 20 hours with a capacity of battery 2000 mAh. Research done by Mazumder *et al.*[11]design a wireless insole foot pressure for various physical activities using capacitive force sensors. The system used wireless RF module XBEE for data transmission. A wearable plantar pressure measurement system has been developed by X. Wang *et al.*[12] The system designed for locomotion recognition, for example walking, standing, sitting, and etc. This system transmits the signal wirelessly at 434 MHz with a data rate of 250 kbps. Results show that the system has a high accuracy rate above 90% using the confusion matrix. Saito *et al.*[13]developed an insole with seven pressure-sensitive conductive rubber sensors with wireless data transmission. The power source used lithium battery, 3V, 850mAh can operate continuously for 20 hours. The device is low cost and can be prepared to fit many shoe sizes. Wahab *et al.*[14] developed a low power gait measurement system. The system is used Inertia Measurement Unit, ultrasonic sensors, ceramic based piezoelectric sensors array, Xbee module, and Arduino as processing unit. The research is focuses on design and development of low power ultra-portable shoe using MEMS technology. The system used lithium polymer battery that can be used up to 4 hours and it is rechargeable. The gait measurement system can be used outdoor/indoor environment. The research[15] has been adopted as an enhancement tool in electronic design phase of this research, while we've addressed the researches[16-18], that were produced by the sub authors of this research, as guide when the sensors calibration and destruction over the insole has been implemented.

The objectives of the research are as follows; To investigate best solution for data transmission from the insole planter prototype and the data analysis station. To achieve a high sampling rate that fulfill the transfer of the data accurately. To ensure that the power consumption is smaller than past because low power consumption components has almost light weight and compact in size. To enhance the diagnosis procedure with a suitable GUI and hardware user flexibility. To make the patient or user more comfort when he/she uses or wear this shoe.

2. System Components and Data Acquisition System Design

2.1. System Components and Block Diagram

The main diagram of the proposed system can be demonstrated as shown in Fig. 1. A four force/pressure sensors were connected in a specific effective location over the touch insole area. The sensors were calibrated in such a way that its relative conditioning circuit output has a maximum value at that point, that's mean the calibration procedure has been implemented individually based on several trials to estimate the maximum force which might applied on that location. As mentioned above, the gain setting of the conditioning circuit is not identical, but it is governed by the test point location. This type of calibration enhances the accuracy of the measurements.

2.2. In-shoe Pressure Sensor

The FlexiForce A201 (by Tekscan) is selected as it has good force sensing properties, linearity, hysteresis, temperature sensitivity, and drift. Its thin construction and flexible make installation inside shoes are easy. The sensing area is 9.53 mm diameter. The sensor acts as a force resistor in the circuit. The resistance will decrease when a force is applied to its sensitive area. The resistance of the sensor will be high when it is unloaded.

2.3. Electronics Module

As shown in Fig. 1, the wireless component that functioned as a data acquisition circuit connected directly to the sensor signal conditioning circuit and the research proposed a method to utilize the options and capabilities which the XBee has to process the collected signals from the sensors and converts these values through its own 10-bits ADC. There were two main factors that recognize research in the use of ZigBee; the environment software program which is only Matlab, and the utilization of the capabilities to use it in this application.

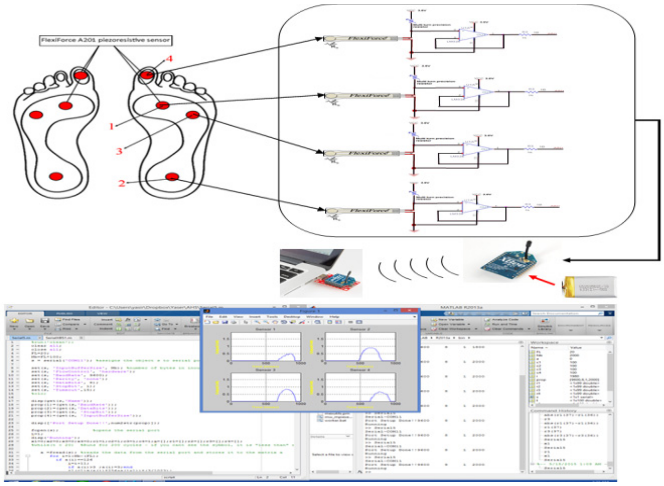

Fig. 1: Represents the main components of the system

2.4. Matlab User Interface Design

By using the Matlab functions, we can access the sensor data without any extra environment software to satisfy the communication between the radio nodes. We have used Matlab's versions 2013a which provide high serial communication functionality. To communicate with serial of an external device from Matlab, the following steps needs to be performed. First, serial port object needs to be created to identify the specific serial port of the PC connected to the external device, then we need to specify how this serial port is to be configured (i.e., number of data bits, baud rate, etc.). Second, the serial port object created above need to be connected to the external device. Third, sending a command signal to the external device and receive data from the external device. Fourth, disconnecting of serial communication connection from the external device and close the serial port object. Finally, release control of the serial port.

3. Methodology

3.1. Pressure Sensor Conditioning Circuit

Referring to Fig. 1, one of the most important thing which should have been taken in our account when we selected each active component is the single voltage supply and the minimum power consumption. So the design of the signal conditioning circuit would be as shown in Fig. 2.

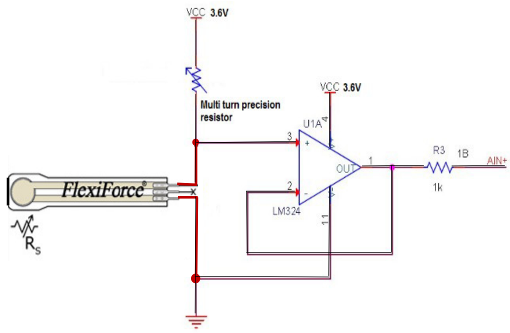

Fig. 2: Force/Pressure sensor signal conditioning circuit.

As it is shown in Fig. 2, multi-turn precision resistor has been used to connect it to the sensor as a voltage divider supplied with 3.6V, which is the lithium ion polymer battery standard voltage. The single supply operation amplifier which is selected in our developed circuit is connected as a voltage follower to overcome the drop due to the impedance mismatching.

3.2. XBee Module

The power supply voltage range between 2.8V - 3.7V of the XBee module, sometimes we need to regulate the voltage to 3.3V before we could start the communication through stabilizer with an output of 3.3V in the control circuit. We have used pins 20, 19, 18, and 17 (analogue input pins) with a reference voltage equal to the XBee biasing voltage (3.3V) so as to reduce the components and attain the full range of the input analogue voltage.

We have used XBee RF Module, 1mW and a suitable XBee explorer USB interface card to connect to the PC for configuration and accessing the data. We used X-CTU software, from DIGI International, creates during installation USB serial port (COM) together with our USB adapter. X-CTU software could be used to set the parameters directly and to connect the module. By using the X-CTU software, we've configured one XBee as a coordinator, which is connected to the computer and driven by Maltab software, whilst the other one configured as an End device to be connected to the four pressure sensors through their conditioning circuits as shown in Fig. 1.

3.3. Prototype Construction

To test this proposed design experimentally, we have select suitable sport shoes which has a space to place the system components on and comfort for user. The components were assembled as shown in Fig. 3.

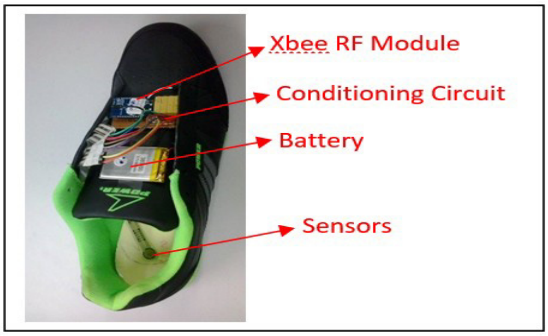

Fig. 3: Measurements and Transmission Components

Fig. 4: Final proposed prototype

While the complete one would be as shown in Fig.4, where the sensors are covered with thin protected layer to ensure their functionality and far from damage, this prototype is not represents the industrial prototype.

1. Power source: The most important factor here is the energy density of the power source, which is the amount of energy stored in a given system or region of space per unit volume or mass, it have been selected with 800mAh to maintain about 22.4 hours at maximum power operation. It also has very light weight and flexibility to be installed in small area.
2. XBee RF module: which consumed 1mW of power and can be functioned on power saving mode when it is switched to sleep mode if configured to operate only on action signal.
3. Electronics component: one IC chip with four op-amps have been selected to use in the sensor signal conditioning circuit.

4. Results and Discussion

1. Essential ADC resolution by suitable conversion time, so as to get smooth output voltage which can be given in the following equation;

If you supply the 10-bits ADC of XBee with 3.3V and your reference voltage same as voltage supply then in case of 10 bit ADC, you have 2^{10}-1= 1024 - 1 = 1023 steps for 3.3V. Thus, 3.3V / 1023 = 3.225 mV (each step of ADC represents 3.225 mV).

As results, the resolution of ADC is 3.225 mV. Therefore, x steps of ADC represent x*3.225 mV.

2. As smaller as sampling frequency or sampling rate, f_s, (average number of samples obtained in one second (*samples per second*), thus $f_s = 1/T$).

In our application and referring to Fig.5, for each enabled analog line, there will be a 2 byte data. In this proposed case, we have enabled 4 analogue input pins in the remote end device, then we've received 8 byte data as part of analogue sample. If the value of Analog Channel Mask is 0x00, then this field will not have any value. The sample data is in HEX format, which we've converted and scaled, to get the exact voltage value. The ADC is 10 bits, ranging from 0-3FF. First convert the hex to equivalent decimal (e.g.: 0x022E = 558 in decimal), then applying formula, Voltage = (Equivalent Decimal value x V_{ref})/1024. Thus, Voltage = (558 x 1.2)/1024 = 0.6539 volt.

The sampling frequency which has been adopted is 20 ms which is the minimum allowed sampling rate in XBee S1 RF module, this value is essential to get smooth and accurate results.

Let us suppose that humans tend to walk at 0.5 m/s. Which means about 1 steps/sec. So, the sensors signal duration is equal to 1000 msec. Thus, number of samples are= 1000/1 = 1000 samples.

3. Matlab Software driver has been attempted only to drive and monitoring the results as shown in the Fig 6.

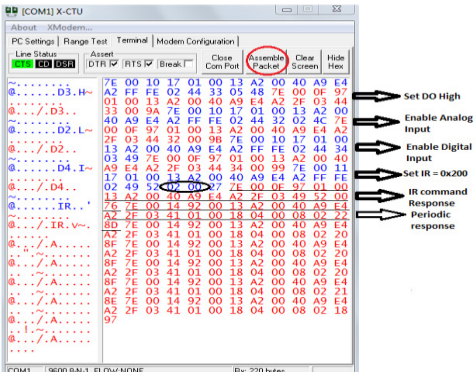

Fig. 5: Sample of serial com. data at the base XBee (receiver).

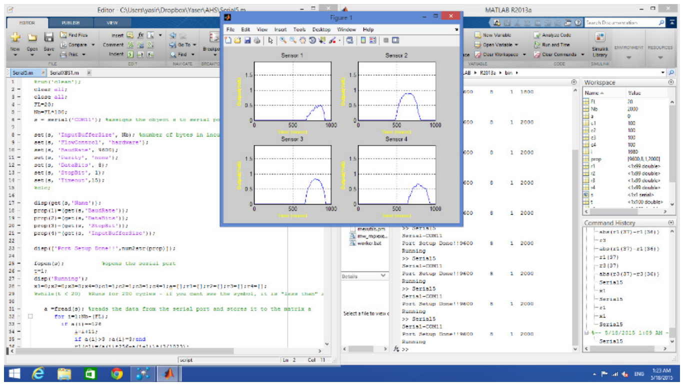

Fig. 6: Four Sensors output waveforms of one step walking.

4.1. Analysis and Comparison with Previous Work

Table 1 shows the comparison of technique for data transmission between worked done by others and our work.

Table 1: Comparison technique used by previous work and proposed work

Reference Number	Technique Used	Voltage Supply (Volt)	Operation time (Hours)
Crea, S. *et al.*(4)	Bluetooth	3.6 V	20 h
Mazumder, O.*et al.*(11)	Xbee+ MUC	-	-
Wang, X.*et al.*(12)	Wireless Module	-	-
Saito, M. *et al.*(13)	Wireless Module	3 V	20 h
Wahab, Y. *et al.*(14)	Xbee+ arduino	3.3 V	4 h
Proposed	XbeeS1 RF 802.15.4	3.6 V	22.4 h

4.2. Accuracy Validation between Oscilloscope and Proposed Wireless Measurement

Fig. 7 and 8 show the results of sensor 1 that were measured by using oscilloscope one time and Xbee RF on another time for the purpose of comparison. In order to increase the accuracy, the output data of sensor 1 have been sampled based-on two different mediums as shown in the graphs which are obtained from calibrated oscilloscope and MATLAB. As resulted, both figures show the similarities at the output. The accuracy of the proposed wireless data acquisition circuit, which utilizes the Xbee RF Module, has been approved in this experiment. In addition, the results obtained from wireless connection is more accurate and smoother as compared with the wired one (data from oscilloscope).

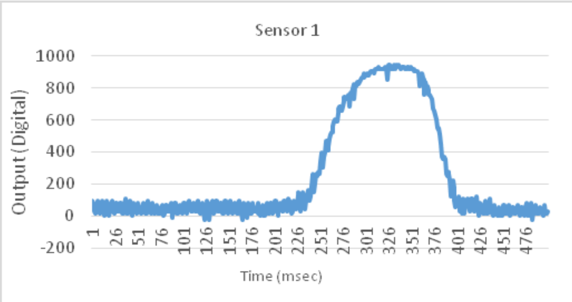

Fig 7: Output Sensor 1 from oscilloscope

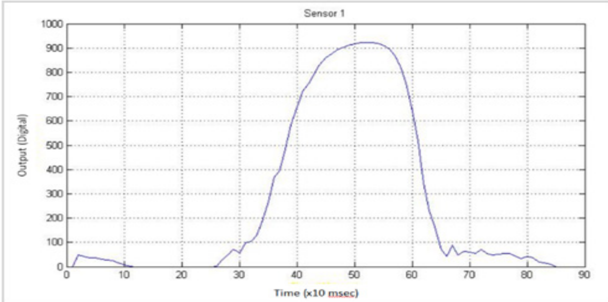

Fig 8: Output Sensor 1 from wireless connection

5. Conclusion

In gait analysis application, the need for an accurate measurement of the foot plantar pressure is important in terms of power source energy density, system compact sizing, component weight, and complexity. The research results show a significant difference in complexity only when based on XBee capability to process the sensor data. The developed system consists of 4 resistive pressure sensors attached to an in-sole for foot. High speed rate and very low power consumption data process made this technique useful for this application. Light weight lithium ion polymer, 16 gm, 2.96 W.h, 3.6V can operates the data acquisition and XBee S1 RF remote circuit about 22.4 hours. Significant purity for the measured data have been obtained when the wireless based Xbee RF attempted, the noise of the environment has an impact on the oscilloscope cables more than that influence on the proposed wireless method. The real time curves that represent the sensors applied force over the time can be used in different diagnostic applications to enhance the human health care monitoring in future.

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